—and of Monge long previously. In this paper it is applied, first to the non-analytical exposition of the differential criteria of algebraic functionality given by Jacobi, and then to the discussion in a similar manner of the theory of partial differential equations of the first and second order, particularly those named after Lagrange, Monge, and Ampère.

VI. "On the Power of Contractility exhibited by the Protoplasm of certain Plant Cells." (Preliminary Communication.) By WALTER GARDINER, M.A., Fellow of Clare College, Cambridge, Demonstrator of Botany in the University. Communicated by Prof. M. FOSTER, Sec. R.S. Received November 21, 1887.

In a former communication ('Roy. Soc. Proc.,' No. 240, 1886), some account was given of the principal changes which take place in the gland cells and stalk cells of *Drosera dichotoma* during secretion. The present paper deals with certain experiments and observations which were undertaken in order to attempt to ascertain by what mechanism the bending of the tentacles is made possible in *Drosera*, and what changes occur in the tentacle cells.

During actual movement no obvious histological changes can be detected in the cells of the bending portion, but when the tentacle has become well inflected, it becomes apparent that the cells of the convex side become more, and those of the concave less turgid than before. Some time after stimulation, and when the period of aggregation has set in, it can be observed that the cells of the convex side are less aggregated than those of the concave. Having ascertained that of the dye solutions, eosin, and of salts, the salts of ammonia, are readily sucked up into the tissue, it was further noticed that in stimulated tentacles the cells of the convex side readily allow the solutions to penetrate, while those of the concave are only penetrated with great difficulty. Thus in the case of a stimulated tentacle treated with eosin, the convex cells are stained long before the concave, and with ammonic carbonate the tannin of the convex cells may be precipitated while the concave cells remain normal, or the convex cells may even be killed while the concave cells remain alive. Thus after stimulation certain changes have occurred in the concave cells of the bending portion, and one result of this change is an increased impenetrability of the primordial utricle. In my former paper I have shown that the tentacle cells of *Drosera* are very sensitive to contact, for if the gland cells be slightly crushed, all movement of the stalk cells ceases for a time, and the spindle-shaped rhabdoid contracts and tends to become spherical. Bearing in mind also the very pro-

nounced inflection which is occasioned by the stimulus of contact or food, by electrical stimulus or, as Darwin has shown, by the stimulus of temperature, one is led to ask whether these phenomena are not associated with true contractility, and whether the increased impenetrability of the protoplasm of the concave cells is not occasioned by a definite contraction of the primordial utricle and a consequent decrease in the size of the molecular pores.

Experiments were then made upon the pulvinus of *Mimosa pudica.* Small pieces of stem (bearing leaves) were cut under a watery solution of eosin, and the pulvini were maintained in a state of stimulation. When the eosin had sufficiently penetrated, transverse and longitudinal sections of the pulvinus were made and examined. It was then seen that the dye had readily penetrated into and stained the protoplasm of the outer cells of the convex side of the pulvinus, while on the concave side no staining whatever, of that tract of cells situated towards the more external portion, which especially play an active part in movement, had taken place. The more indifferent cells immediately surrounding the vascular bundle also show some contrast in coloration, for in the upper half this tissue remains unstained, while in the lower half some staining occurs. Thus by the process of staining the seat of the especially irritable tissue was clearly brought into view. The author now commenced electrical experiments with the pulvini. Two small pins (which were found not to injure the tissue to any appreciable extent) were inserted into the irritable tissue —one at each end, and fine wires from these pins communicated to the various electrical apparatus as required. When suitably stimulated with either a constant current, an induction shock, or a tetanising shock, the leaf fell immediately contact was made. With the single induction shock the breaking shock was found to be a stronger stimulus than the making. A small piece of stem with the pulvinus attached—the lamina and a portion of the petiole of the leaf having been previously removed—was attached to a lever which wrote upon a revolving drum. On throwing in the electrical stimulus the pulvinus contracted and a curve was obtained. The pulvinus was then turned upside down and, after recovery, was again stimulated and a second curve obtained. In both instances the pulvinus raised a weight greater than that of the leaf and leaf stalk. These experiments for the most part only confirmed those of Cohn and Kabsch, except that they were carried out in further detail; but one new and important observation was made, viz., that under the influence of a feeble tetanising current the period of recovery of the pulvinus could be materially shortened, and the leaf could be induced to assume the position before stimulation in less time than it would have taken under ordinary circumstances. The wonderful delicacy with which the irritable cells of the pulvinus at once reply to stimulation, the fact that in their reaction to the

stimulus of electricity they obey the same laws as animal muscle, and, like certain muscles, may also be relaxed by a feeble tetanising current, go far to suggest that in dealing with the movements of the pulvinus of *Mimosa* we have essentially to do with the phenomenon of contractility.

Although the foregoing results may be said to favour the idea that in irritable organs, movements are brought about by a definite contraction of the protoplasm of the cells of the irritable side, yet the author felt that the matter could only be set at rest by still further strengthening the evidence, and if it were possible, by the actual observation of a cell contracting under the influence of electrical or other stimulation. He therefore turned his attention to the simple filamentous Algæ, and among them to an organism which he believed would be peculiarly sensitive to stimulation, viz., *Mesocarpus pleurocarpus.* The filaments consisting of rows of cells were first experimented upon, electrically. A single induction shock of moderate strength was found to cause a splitting apart of the previously united transverse walls of the contiguous cells along the middle lamellæ. In each cell, the two end walls now project inwards towards the centre of the cell in a concave manner, so that between each pair of cells of the filament there arise a series of double convex lenticular spaces. The rupture does not extend to the free surface.

With a stronger shock so much contraction is produced that the cells actually fly apart and a complete rupture is effected. The end walls of each cell are now observed to be slightly convex instead of concave. This is a result of the contraction of the freed edges of the external walls, which in consequence of the rupture no longer maintain their cylindrical form. Each cell now resembles a cylinder with its two ends somewhat convex, and its sides very slightly contracted in the immediate neighbourhood of their lines of union with the ends. As in *Mimosa* the breaking is a stronger stimulus than the making shock. Similar contraction is obtained with the tetanising shock and with the constant current.

Sudden illumination, sudden rise of temperature (45—50° C.), and the stimulus of certain poisons, bring about the contraction and breaking apart in the most marked manner. Of the poisons, camphor, quinine, strychnine, physostigmine and strong alcohol were found to be exceedingly powerful, with very dilute alcohol no obvious change occurred. The strongest plasmolysing reagents did not bring about the rupture of the cells, but only the partial separation of the end wall, and if the cells are killed by boiling water, by iodine, or by very dilute chromic acid (0·25 per cent.), similar results follow. With 1 per cent. osmic acid or 1 per cent. chromic acid the cells may be killed and fixed with little or no contraction.

The results with plasmolysis entirely agree with those previously

obtained in the case of *Drosera* (*loc. cit.*): the protoplasm seeming to be partially paralysed, the whole of its energy apparently expended in endeavouring to protect itself from the abnormally rapid withdrawal of water. The passive shrinking produced by strong dehydrating reagents is essentially different from the active contraction arising from normal stimulation, and one may well inquire whether the effects produced by plasmolysis at all tally with those vital processes which actually take place under ordinary circumstances in plant cells.

The results obtained with *Mesocarpus* demonstrate that we have here a plant cell which reacts in a most powerful manner to the stimulus of temperature, of light, of electricity, and of poisons, and that this reaction, which may be watched under the microscope, is attended by a diminution in size. In the opinion of the author such a series of reactions can only point to one property of the protoplasm, viz., that of contractility, and taking into consideration the whole of the observations, there appears to be no doubt that the protoplasm of plant cells, like that of animal cells, is capable of active contraction. The author believes that in all irritable organs the movements are brought about in consequence of a definite contraction of the protoplasm of the irritable cells, and that during such contraction some of the cell sap escapes to the exterior. At the same time the elastic cell wall contracts *pari passu* with the protoplasm. The author has already drawn attention to the intimate connexion between the protoplasm and the wall ('Phil. Trans.,' 1883, Part 3), and has shown that even after pronounced plasmolysis, the ectoplasm of the primordial utricle is always connected to the cell membrane by very numerous and delicate strands of protoplasm. The protoplasm may be withdrawn from the wall by a very strong electric shock, but the normal effect of a moderate stimulus is to cause the protoplasm to contract, and in certain cases pull upon its wall, while in very turgid cells where the cell wall is in a state of great tension, the wall for the most part simply contracts upon the protoplasm. The escape of liquid from the interior of the cell is regarded as being due to filtration under pressure. The author is unable to uphold Pfeffer's theory that the sudden abolition of turgidity is dependent upon the destruction of a certain quantity of an osmotically active substance. In his opinion there is in every cell a sufficient quantity of osmotically active substance to ensure turgidity, but the increase or decrease of turgidity essentially depends on the contraction or relaxation of the primordial utricle. His experiments all tend to show that it is the ectoplasm which mainly determines the state of turgidity of the cells. Thus in the tentacle cells of *Drosera* the endoplasm may actually be withdrawn from the ectoplasm by the lengthy action of strong solutions of magnesium sulphate, and although it is almost

entirely collected around the nucleus at the centre of the cell, the latter still remains turgid.

The author is also of opinion that de Vries' view, that the turgidity of the cell is mainly dependent on the presence of certain osmotically active substances in the sap, of an acid nature, requires some further qualification, for his own results agree rather with those of Schwartz, since he finds that turgid cells may possess either an acid or an alkaline sap. Thus, in *Drosera* itself, the cells of the tentacles have an acid, and those of the petals of the flower an alkaline reaction.

Finally, the author believes that the property of contractility, which he claims to have established for the irritable cells of *Drosera* and *Mimosa*, and for the less specialised cells of *Mesocarpus*, is a property which is possessed in a greater or less degree by all the actively living cells which constitute the tissues of plants. The important bearing of these results on all phenomena of movement and growth is sufficiently obvious. The author hopes to deal with the matter in fuller detail in a future paper.

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